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THREE-DIMENSIONAL MECHANICAL MOUSE

FIELD OF THE INVENTION

5 The present invention relates to a computer-human interface device, and more particularly it relates to a stylus coupled to a supportable mechanical linkage for providing commands to a computer.

BACKGROUND OF THE INVENTION

10 As the use of Computer Aided Design (CAD) Systems becomes more widespread, the need for cursor and command control devices which accurately and easily track three-dimensional position or motion is also growing. Devices which allow users to control a cursor with three-dimensional position and/or orientation commands are available for various applications. Among them are many hand-held input devices which allow users to interact with a host processor by controlling the position of a cursor or manipulating graphic objects on a computer screen. While these devices allow three-dimensional information to be transmitted to a computer they do not allow
15 the user to use gestures and motions which are natural to the user.

20 For example, a prior art device of the type which is used for three-dimensional control involves the use of accelerometers to transduce the position and orientation of a stylus in space as described in U.S. Pat. No. 4,839,838. This device makes no provisions so the stylus can be grasped in a manner which makes use of finger dexterity nor does it include mechanical support to reduce fatigue or enhance user control or dexterity.

Another prior art example is an ultrasonic position-locating device like the one shown in U.S. Pat. No. 5,142,506. This device transduces position and orientation by triangulating ultrasonic signals. As with the prior art previously described, this device uses a free-floating stylus which includes no provisions for mechanical support to reduce fatigue or enhance user control or dexterity. Furthermore, this device is used with a stylus that is grasped in the palm of the hand. The use of such a stylus precludes fine positioning with the fingers and greatly reduces the dexterity of the user to manipulate position and orientation. In addition, this device is used with digital buttons on the stylus to send to the computer command signals. A button of this type is commonly called a "clicker" on a "mouse." Because such buttons are mechanically coupled to the free-floating stylus, it is difficult to push the buttons while maintaining the position and orientation of the stylus. By pushing down on the button, the user will necessarily move the stylus from its desired position. Accordingly, these commands are difficult to control under many circumstances.

SUMMARY OF THE INVENTION

In the present invention, the user holds a stylus which is supported by a support apparatus on a fixed surface so that the user can easily manipulate the stylus in free space to interact with a computer. The three-dimensional motion of the user is translated through the stylus and mechanical linkage to a processor which communicates with the computer, thus allowing commands to be sent to the computer which track the three-dimensional motion of the user. Therefore, cursor control in three-dimensions on the two-dimensional computer screen is possible.

In one embodiment, the stylus is supportable on a fixed surface by a set of mechanical linkages which include individual components joined together by a sufficient number of joints to allow several degrees of freedom in the motion of the stylus. These mechanical linkages provide mechanical leverage, friction, counter-weighting, and/or spring resistance in order to reduce fatigue of the user and

to provide support to enhance the stability and dexterity of user manipulation of the stylus.

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In the aforementioned embodiment of the present invention, the joints of the mechanical linkages are coupled to sensors which provide information about their position. Such information is transmitted to a microprocessor so that position and orientation of the stylus can be computed using kinematic equations associated with or related to the particular linkage system. In another embodiment, position and orientation of the stylus is sensed through the use of ultrasonic, magnetic, or optical position and orientation sensors mounted on the stylus.

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Another aspect of the present invention includes a remote control unit which is used in place of a command clicker on the stylus. For example, a foot pedal or hand-held unit for the user's opposite hand is included to provide command control to the computer. Accordingly, manual dexterity of stylus manipulation is not compromised.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of an embodiment of the present invention;

Figures 2A and 2B are block diagrams over-viewing two different electronic hardware configurations of the present invention;

5 Figure 3 is a flow chart describing the main software loops for two different electronic hardware configurations shown in FIG. 2;

Figures 4A and 4B are flow charts describing two different interrupt service routines for serial output to host computer;

10 Figure 5 is a perspective representation of another embodiment of the present invention;

Figure 6 is a perspective view of still another embodiment of the present invention;

Figure 7 is a perspective representation of another embodiment;

Figure 8 is a perspective view of another embodiment;

15 Figure 9 shows an embodiment of the resistance mechanism of the present invention;

Figure 10 shows another embodiment of the resistance mechanism; and

Figure 11 shows yet another embodiment of the resistance mechanism.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIG. 1, a stylus 11 is shown attached to a support apparatus which is, in turn, supported on a fixed surface. By electrical and electronic configurations described below, the stylus 11 is adapted to provide data from which a computer or other computing means such as a microprocessor can ascertain the position and orientation of the stylus as it moves in three-dimensional space. This information is then translated to an image on a computer display apparatus. The stylus 11 may be used, for example, by an operator to change the position of a cursor on a computer controlled display screen by changing the position and/or orientation of the stylus, the computer being programmed to change the position of the cursor in proportion to the change in position and/or orientation of the stylus. In other words, the stylus 11 is moved through space by the user to designate to the computer how or where to move the cursor on a computer display apparatus.

The stylus 11 is a pen-like stick which can be manipulated between the fingers, allowing for much better control and fine dexterity as compared to full hand grips or palm-supported styluses used by some prior art inventions. While the stylus 11 is described in terms of manual manipulation, other stylus configurations are envisioned by the present invention. In particular, this invention includes manipulation by those unable to manually manipulate a pen. A stylus of the present invention, need not be linear, but may be curved or angled so that it may be held, for example, by the foot or the mouth of a person.

Because the stylus is supported by a support apparatus which is in turn supported by a fixed surface or other stabilizing configuration, the user can manipulate the stylus with a minimum of effort. Also, if the user chooses to discontinue using the stylus, it is capable of maintaining its position in space, unattended. While FIG. 1 shows that preferred embodiment of the present invention, FIGS. 5-8 show alternative embodiments, such which are also contemplated under the present invention. It is preferable that the stylus have enough degrees of freedom to enable it to move through the mechanical linkage to give the user the amount of flexibility needed to move the cursor as desired. In FIG. 1, six degrees of freedom are shown and are

labeled as Axis' 16. This, of course, provides maximum flexibility. Fewer degrees of freedom, such as a plurality of degrees of freedom, may also be sufficient depending on the application.

5 In one embodiment, the stylus is connected to rigid individual components which are joined together by joints. While not shown, other types of support apparatus' are included in the present invention. For example, other configurations include a semi-flexible rod or any other moveable while supportive configuration which can support the stylus in the manner described herein.

10 In FIG. 1, a mechanical linkage pursuant to the present invention is depicted. The stylus 11 is coupled to supportable mechanical linkages via joint 12 which, in the shown embodiment, houses sensors 13A and 13B. Linkage 14, is connected, via joint 15 having position sensors 16A and 16B, to linkage 17. Joint 18 in turn connects linkage 17 with the vertical base protrusion 20 which emanates from the base 21. The sensors are used to produce a stylus locative signal which is
15 responsive to and corresponds with the position of the stylus at any point in time during its normal operation. The stylus locative signal is used to provide information for use by a computer display apparatus of a computer. The term "joint" as used herein is intended to mean the connection mechanism between individual linkage components. In fact, two separate moveable members can be joined; such together
20 forming a joint.

The base 21, if necessarily, can be immobilized by securing it onto the fixed surface 23 by way of bolt, screw or other attachment mechanism 22. Moreover, the present invention implements mechanical leverage and rubbing friction (not shown) between the supportable mechanical linkages 14 and 17 and the joints 12, 15 and 18
25 in order to provide resistance and support so as to allow better dexterity than can be achieved with free-floating stylus trackers. This support and leverage aids in reducing the fatigue associated with manipulating the free-floating stylus 11.

As mentioned above, attached to each joint 12, 15 and 18 are sensors 13A, 13B, 16A, 16B, 19A, and 19B, respectively. These sensors sense the angle differential before and after motion of the two segments connected by that joint. The sensors can be, for example, optical incremental encoders, optical absolute encoders and potentiometers. Because the three-dimensional position and/or orientation tracking is achieved mechanically, this preferred embodiment avoids problems that magnetic and ultrasonic sensors, such as those shown in the prior art, encounter with metal and shadowing. However, as shown in FIG. 1, if desired, sensing means can be used to track the position and/or orientation of the stylus by mounting a single or several orientation sensors in the stylus 11 itself, such referred to as a stylus mounted sensor 11. An ultrasound, magnetic, optical or position and orientation sensor can be used as the stylus mounted sensor 11.

FIG. 1 also shows a clicker button 24 on stylus 11. The button is connected to a switch which when in the on state, sends a signal to the computer giving it a command. In order to provide for accuracy when sending commands, this invention also includes a remote clicker unit. Therefore, since the clicking motion occurs at a distant location from the cursor control, there is little or no opportunity to accidentally move the cursor while making a command. FIG. 1 shows two configurations for implementing this aspect of the present invention. The first is identified as an alternate hand-clicker 25, the second as foot pedal 26.

Digital buttons 27 and 28 which are connected to switches (not shown) on the remote attached peripherals such as a hand-held clicker unit 25 or a foot pedal 26, respectively, can generate additional digital input such transmitted through lines 25' and 26' respectively. Either of the shown ancillary remote command units, such including the hand unit 25 and the foot pedal 26 configurations, are favorable methods of inputting digital commands by command hardware or software (not shown) because pressing the button 27 or 28 does not compromise a user's ability to hold the stylus steady whereas pressing any button 24 on the stylus does compromise stylus stability.

Referring to FIG. 2A, the sensors 13A, 13B, 16A, 16B, 19A and 19B, along with any peripherals 24, 25 or 26, can send their digital signals directly to a versatile floating-point processor or microprocessor 32A which is controlled by software stored in a digital ROM (Read-Only Memory) via transmission line 32' or another form of transmission, i.e., radio signals. As shown in FIG. 2B, an alternative embodiment can be used to lessen the demands on the floating-point processor or microprocessor 32B. The digital inputs of the sensors 13A, 13B, 16A, 16B, 19A and 19B can be sent indirectly to the floating-point processor or microprocessor 32B by way of dedicated chips 13C, 13D, 16C, 16D, 19C and 19D, which pre-process the angle sensors' signals before sending them via bus 31 to the floating-point processor or microprocessor 32B which would combine these signals with those from the peripherals 24, 25 or 26. An 8-bit data bus plus chip-enable lines allow any of the angle determining chips to communicate with the microprocessor. Moreover, reporting the status of peripherals 24, 25 or 26 includes reading the appropriate digital switch and placing its status in the output sequence array. Some examples of specific electronic hardware usable for sensor pre-processing include quadrature counters, which are common dedicated chips that continually read the output of an optical incremental encoder and determine an angle from it, Gray decoders, filters, and ROM look-up tables.

The single-chip configuration of FIG. 2A is most applicable where the angle sensors 13A, 13B, 16A, 16B, 19A and 19B are absolute sensors, which have output signals directly indicating the angles without any further processing, thereby requiring less computation for the microprocessor 32A and thus little if any pre-processing. The multi-chip configuration of FIG. 2B is most applicable if the sensors 13A, 13B, 16A, 16B, 19A and 19B are relative sensors, which indicate only the change in an angle and which require further processing for complete determination of the angle.

In either configuration, if the microprocessor 32A or 32B is fast enough, it will compute stylus 11 position and/or orientation (or motion, if desired) on board the embodiment and send this final data through any standard communications interface

such as an RS-232 serial interface 33 on to the host computer system 34 and to computer display apparatus 34'' through transmission line 34' or another form of transmission. If the microprocessor 32A or 32B is not fast enough, then the angles will be sent to the host computer 34 which will perform these calculations on its own.

5 In addition to the single-chip and multi-chip configurations, a variation may consist of a single microprocessor which reads the peripherals, obtains the angles, possibly computes coordinates and orientation of the stylus 11, and supervises communication with the host computer 34. Another variation may consist of dedicated sub-circuits and specialized or off-the-shelf chips which reads the peripherals,
10 monitors the angle sensors 13A, 13B, 16A, 16B, 19A and 19B, determine the joint angles, and handle communications with the host computer 34, all without software or a microprocessor 32A or 32B.

Software is only included in the two microprocessor-based configurations shown in FIGS. 2A and 2B. The more dedicated hardware a given configuration
15 includes, the less software it requires. The software consists of a main loop (FIG. 3) and an output interrupt (FIGS. 4A and 4B).

Referring to FIG. 3, the main command loop responds to the host computer 34 and runs repeatedly in an endless cycle. With each cycle, incoming commands from the host computer are monitored 36 and decoded 37, and the corresponding
20 command subroutines for reporting angles, thus stylus position and/or orientation (see FIGS. 4A and 4B), are then executed 38. Two possible subroutines are shown in FIGS. 4A and 4B. When a subroutine terminates, the main command loop resumes 39. Available command will include but are not limited to: reporting the value of any single angle, reporting the angles of all six angles at one time, reporting the values of
25 all six angles repeatedly until a command is given to cease aforementioned repeated reporting, reporting the status of peripheral buttons, and setting communications parameters. If the angle sensors require preprocessing, these commands will also include resetting the angle value of any single angle or otherwise modifying

preprocessing parameters in other applicable ways. Resetting pre-processed angle values or preprocessing parameters does not require output data from the device. The microprocessor 32A or 32B simply sends appropriate control signals to the preprocessing hardware 13C, 13D, 16C, 16D, 19C, and 19D. If the microprocessor or floating-point processor is fast enough to computer stylus coordinates and orientation, these commands will also include reporting the stylus coordinates once reporting the stylus coordinates repeatedly until a command is given to cease, ceasing
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aforementioned repeated reporting, reporting the stylus coordinates and orientation once, reporting the stylus coordinates and orientation repeatedly until a command is given to cease, ceasing aforementioned repeated reporting. If force reflection is supported, these commands will also include reporting the forces felt by any single joint, setting the resistance of any single joint, and locking or unlocking a joint.

Any report by the subroutines of FIGS. 4A and 4B of a single angle value requires determining 41 the given joint angle. For the single-chip configuration shown in FIG. 2A, this subroutine directly reads the appropriate angle sensor 42 from among sensors 13A, 13B, 16A, 16B, 19A, and 19B. For the multi-chip configuration shown in FIG. 2B, this subroutine reads the outputs 43 of pre-processing hardware 13C, 13D, 16C, 16D, 19C, and 19D which have already determined the joint angles from the outputs of the sensors 13A, 13B, 16A, 16B, 19A, and 19B. Any report of multiple angles is accomplished by repeatedly executing the subroutine for reporting a single angle. The subroutine is executed once per angle, and the values of all angles are then included in the output sequence array. If the optional parts of the subroutines 45 are included, then these subroutines become the coordinate reporting subroutines. Many other command subroutines exist and are simpler yet in their high-level structure.

After determining the given joint angle, the microprocessor 32A or 32B creates an output sequence 44A or 44B by assembling an array in a designated area of processor memory which will be output by the microprocessor's communications system at a given regular communications rate. The sequence will contain enough information for the host computer 34 to deduce which command is being responded

to, as well as the actual angle value that was requested. Returning to FIG. 3, a query 36 in the main command loop asks whether the previous command requested repeated reports. If so, the main command loop is initiated accordingly. The communications output process (not shown) may be as simple as storing the output data in a designated output buffer, or it may involve a standard set of communications interrupts that are an additional part of the software. Setting communications parameters does not require output data from the device. The microprocessor 32A or 32B simply resets some of its own internal registers or sends control signals to its communications sub-unit.

To report the stylus' 11 coordinates, three of the five or six angle values pre-read and knowledge of link lengths and device kinematics are incorporated to compute stylus 11 coordinates. These coordinates are then assembled in the output sequence array.

To report the stylus' 11 orientation, at least five angle values are read and knowledge of link lengths and device kinematics are incorporated to computer stylus 11 orientation. The orientation consists of three angles (not necessarily identical to any joint angles) which are included in the output sequence array.

Forces felt by a joint, setting a joint's resistance, and locking or unlocking a joint are reported by using interaction of the microprocessor 32A or 32B with forced-reflecting hardware (not shown). Reporting forces felt by a joint uses a force sensor mounted on the joint and then places the resulting value in the output sequence array. To set a joint's resistance and locking or unlocking a joint control signals reading from a force sensor to force-reflection hardware but do not require any output data of the device.

Also contemplated in the present invention is computer software and hardware which will provide feedback information from the computer to the stylus (not shown). This type of implementation is known in robotics and thus is easily incorporated into a

system including the present invention. When a surface is generated on the computer screen, the computer will send feedback signals to the mechanical linkage which has force generators for generating force in response to the cursor position on the surface depicted on the computer screen. Force is applied for example, by added tension in the joints which is in proportion to the force being applied by the user and in conjunction with the image on the screen.

The various configurations of the mechanical linkages shown in FIG. 5, FIG. 6, FIG. 7 and FIG. 8 which have different numbers of individual components and joints than shown in FIG. 1 are illustrative of the numerous possible configurations which can provide varying degrees of freedom inherent in the present invention. Referring to FIG. 5, FIG. 6 and FIG. 8, note that a rounded object such as a ball can act as a joint having motion in three degrees of freedom. In conjunction with other mechanical linkages and attachments, this permits sufficient degrees of freedom for the purposes of the present invention. In each figure, the orientation of the degrees of freedom of each joint is depicted by curved lines, numbered consecutively.

Briefly, FIG. 5 shows a rounded joint 46 at the base such that three degrees of motion are available at that joint. FIG. 6 shows a three-dimensionally rotatable rounded joint 47 at the base through which one mechanical linkage can slide linearly and where the base is attached to a fixed surface 48 such that the surface does not prohibitively impede the movement of the device. FIG. 7 shows an embodiment where the basal connection can slide about the base in a two-dimensional plane in the cross configuration 49 on base 51. FIG. 8 shows a three-dimensionally rotatable rounded joint 52 at a perpendicular projection from the base 53 through which one mechanical linkage 54 can slide linearly through the joint 52.

While any of the above discussed configurations or others can be used in accordance with the present invention, FIGS. 9-11 show different mechanisms for providing resistance to the manual manipulation of the stylus by the user. FIG. 9, for example, shows return or tension springs 56 on each joint of the embodiment shown

in FIG. 1. In an alternative embodiment, FIG. 10, shows counter-weights 57 on each joint. Moreover, FIG. 11, shows a combination of a return or tension spring 56, a counter-wight 57 and a compression spring 58. The arrangement of the resistance mechanism used should depend upon the configuration stylus mechanical linkage combination, such arrangement preferably chosen to maximize the ease with which the user can manipulate the stylus 11 in free space in accordance with the present invention.

WHAT IS CLAIMED:

1. A device for use in conjunction with a computer display apparatus and a fixed surface, comprising:

a stylus;

means supportable on a fixed surface and coupled to said stylus for supporting said stylus while allowing at least a plurality of degrees of freedom in the motion of said stylus; and

means for producing a stylus locative signal responsive to and corresponding with the position of the stylus at any point in time during its normal operation, said stylus locative signal providing information for use by a computer display apparatus.

2. A device as recited in Claim 1 wherein supporting means is a mechanical linkage.

3. A device as recited in Claim 2 wherein said stylus locative signal means is in communication with said mechanical linkage.

4. A device as recited in Claim 1 wherein said stylus locative signal means is in communication with said stylus.

5. A device as recited in Claim 1 further comprising:

a remote unit having switch capable of being in an on state and an off state; and

command means triggered by said switch when said switch is in its on state for generating a command signal for receipt by a computer.

6. A device as recited in Claim 5 wherein said remote unit is a foot pedal unit.

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7. A device as recited in Claim 2 wherein said mechanical linkage includes three individual components.

8. A device as recited in Claim 2 wherein said mechanical linkage includes at least three joints.

9. A device as recited in Claim 1 further comprising means for providing resistance to the motion of the stylus.

10. A device as recited in Claim 1 wherein said stylus has pencil-like configuration which can be manually manipulated.

11. A device as recited in Claim 1 further comprising:
feedback means for generating force by said support means in response to force signals provided to said device, said force signals correlated to information displayed on computer display apparatus.

12. A method for interfacing a user and a computer display apparatus, comprising the steps of:
providing a stylus;
coupling to said stylus a support apparatus supportable on a fixed surface for supporting said stylus while allowing at least a plurality of degrees of freedom in the motion of said stylus; and
providing means for producing a stylus locative signal responsive to and corresponding with the position of the stylus at any point in time during its normal operation, said stylus locative signal providing information for use by a computer display apparatus.

13. A method as recited in Claim 12 wherein support apparatus is a mechanical linkage.

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14. A method as recited in Claim 13 wherein said stylus locative signal means is in communication with said mechanical linkage.

15. A method as recited in Claim 12 wherein said stylus locative signal means is in communication with said stylus.

16. A method as recited in Claim 12 further comprising the steps of:
providing a remote unit having switch capable of being in an on state and an off state; and
providing a command signal generator triggered by said switch when said switch is in its on state for generating a command signal for receipt by a computer.

17. A method as recited in Claim 16 wherein said remote unit is a foot pedal unit.

18. A method as recited in Claim 13 wherein said mechanical linkage includes three individual components.

19. A method as recited in Claim 13 wherein said mechanical linkage includes at least three joints.

20. A method as recited in Claim 12 further comprising means for providing resistance to the motion of the stylus.

21. A method as recited in Claim 12 wherein said stylus has pencil-like configuration which can be manually manipulated.

22. A device as recited in Claim 11 further comprising the steps of:

providing feedback means for generating force by said support means in response to force signals provided to said device, said force signals correlated to information displayed on computer display apparatus.

23. In a computer system having a main unit and cursor control functions and command control functions which are triggered remotely from said main unit, a device for interfacing a user and computer, comprising:

5 a remote command control unit separate from a cursor control unit having a switch capable of being in an on state and an off state;

command means triggered by said switch when said switch is in its on state for generating a command signal representative of a command from a user to a computer; and

10 transmission means for transmitting said command signal to said computer.

24. A device as recited in Claim 21 wherein said remote command control unit is a foot pedal unit.

25. In a computer system having a main unit and cursor control functions and command control functions which are triggered remotely from said main unit, a system for interfacing a user and computer comprising the steps of:

5 providing a remote command control unit separate from a cursor control unit having a switch capable of being in an on state and an off state;

generating a command signal representative of a command from a user to a computer when said switch is in its on state; and

transmitting said command signal to said computer.

26. A system as recited in Claim 23 wherein said remote command control unit is a foot pedal unit.

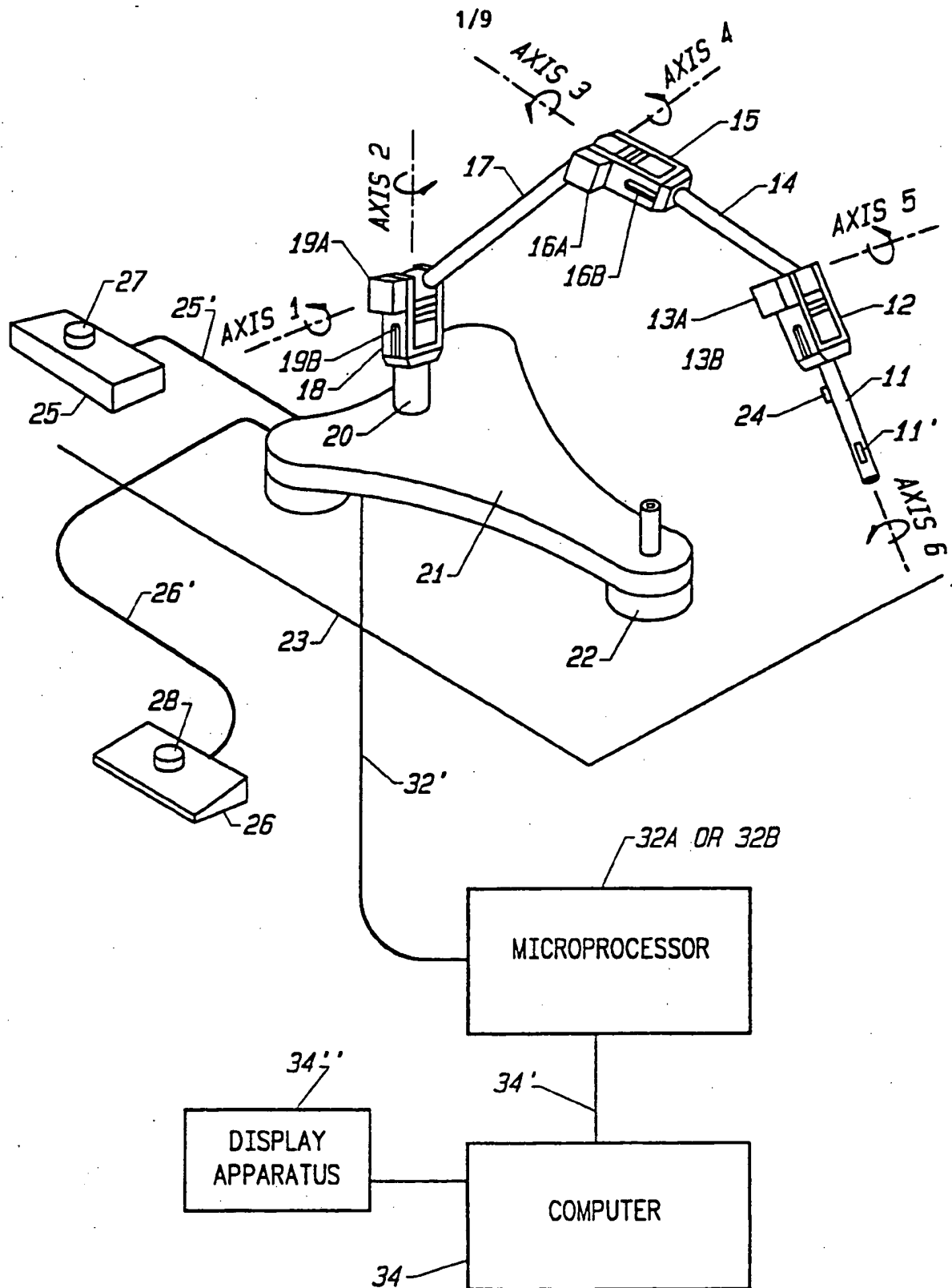
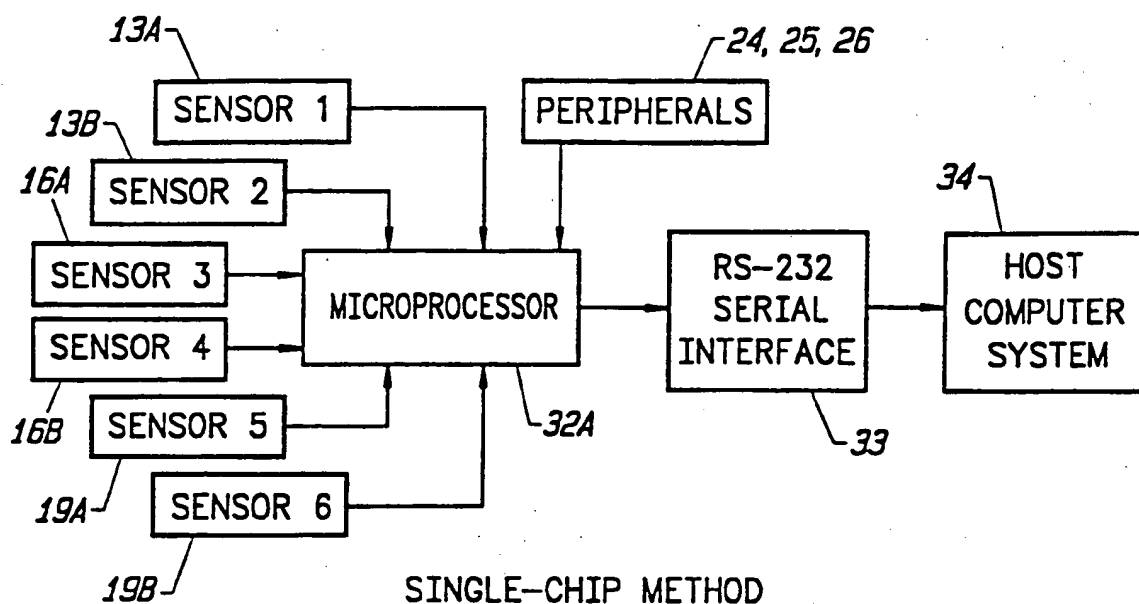
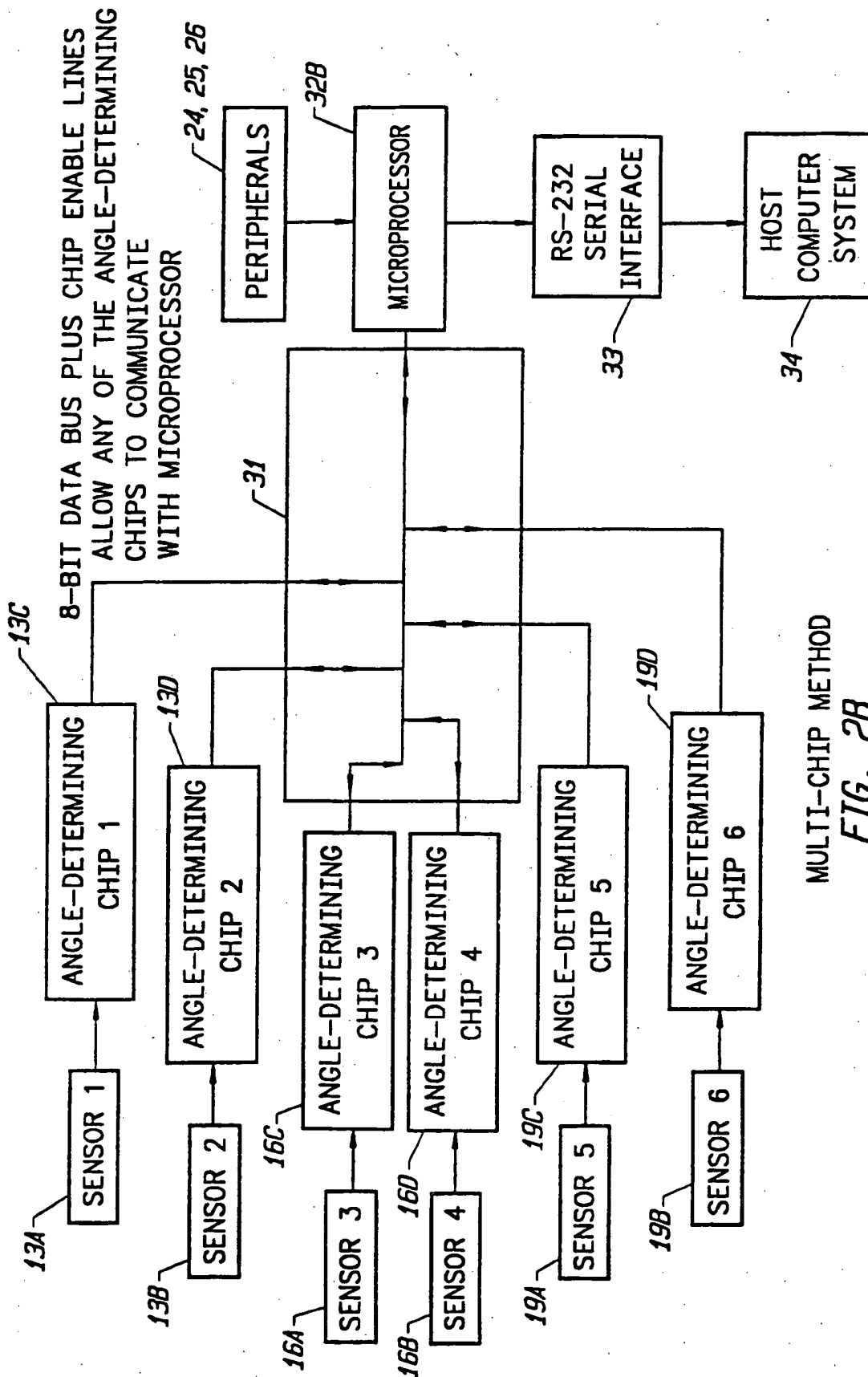


FIG. 1

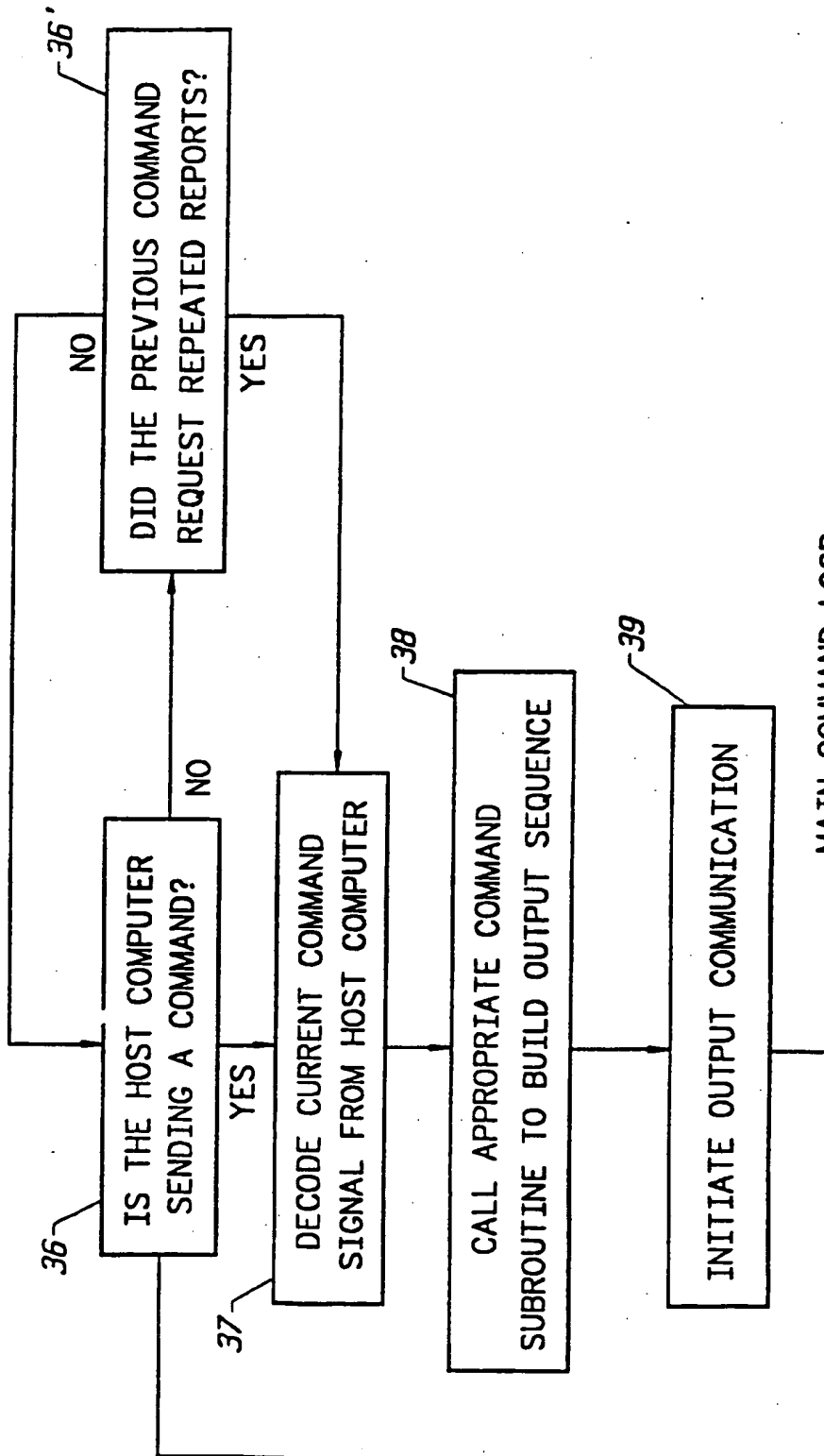
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*FIG. 2A*



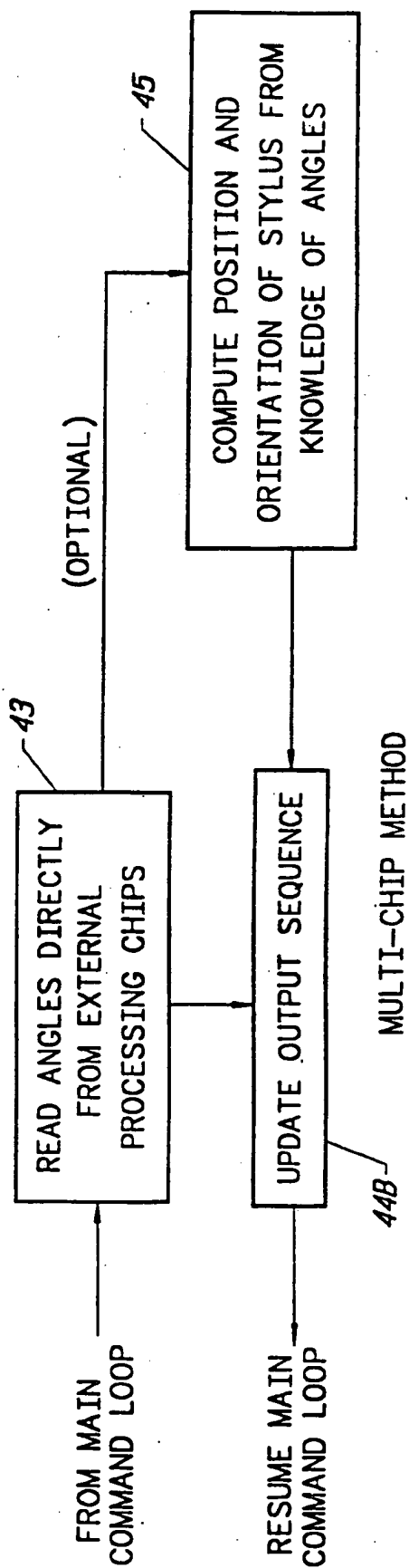
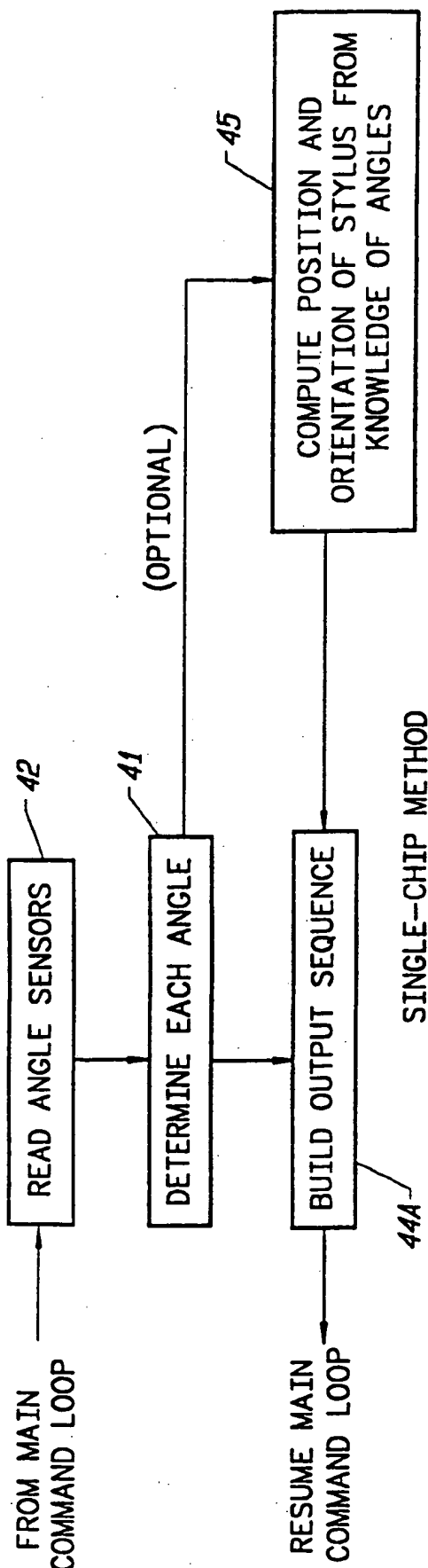
MULTI-CHIP METHOD
FIG. 2B

4/9

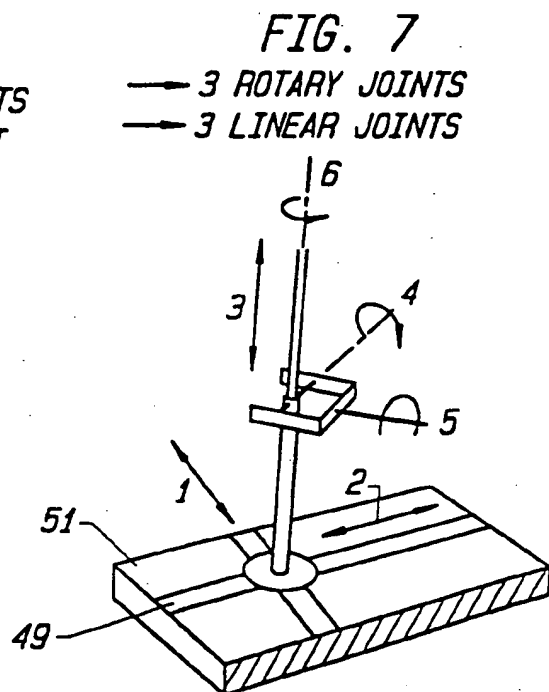
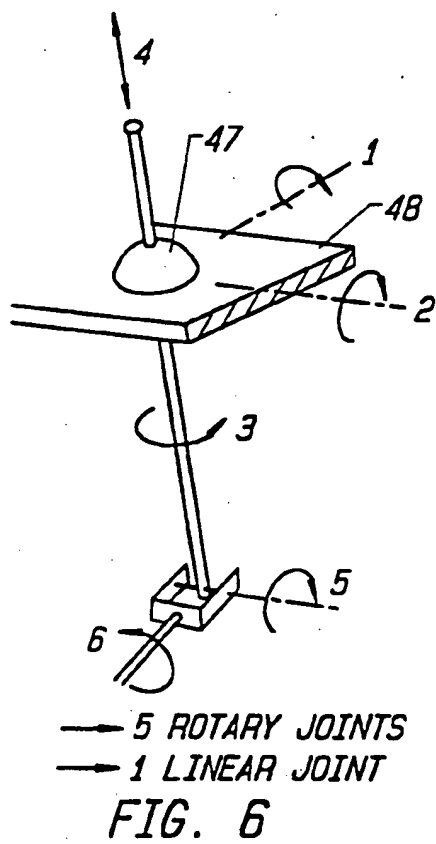
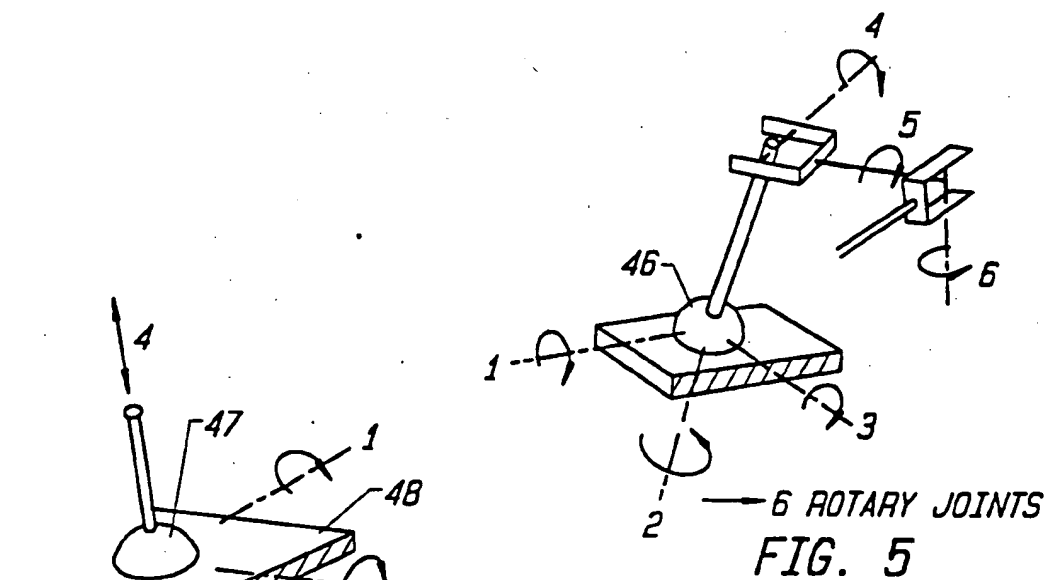


MAIN COMMAND LOOP

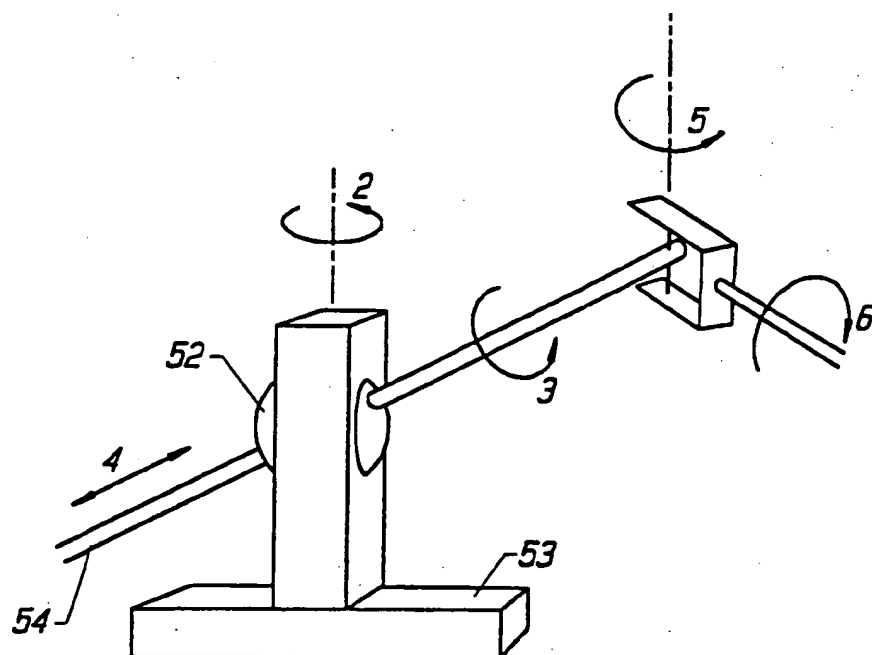
FIG. 3



6/9

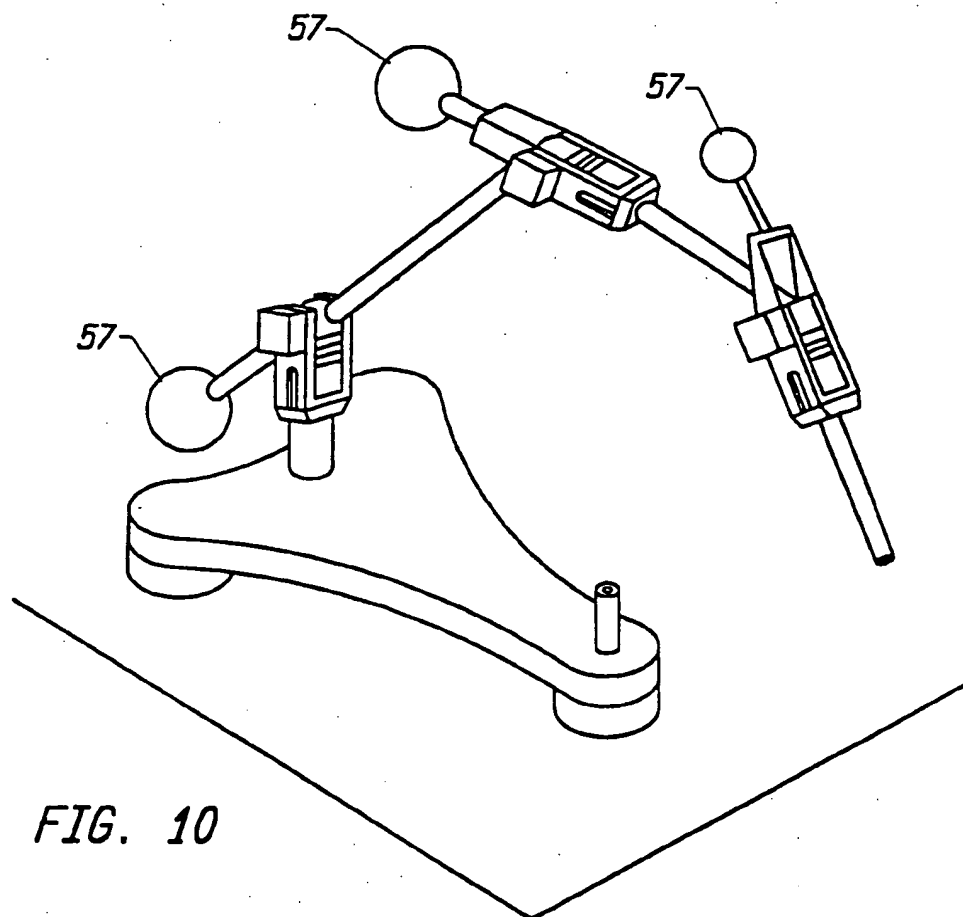
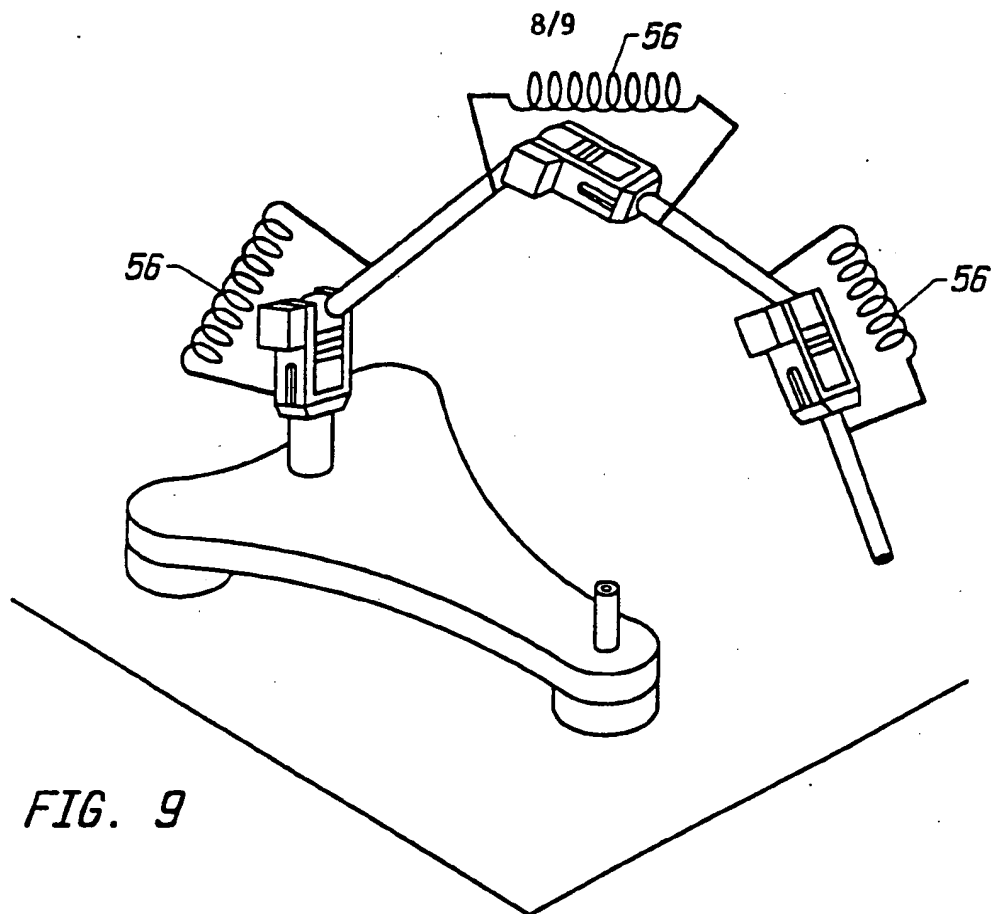


7/9



5 ROTARY JOINTS
1 LINEAR JOINT

FIG. 8



9/9

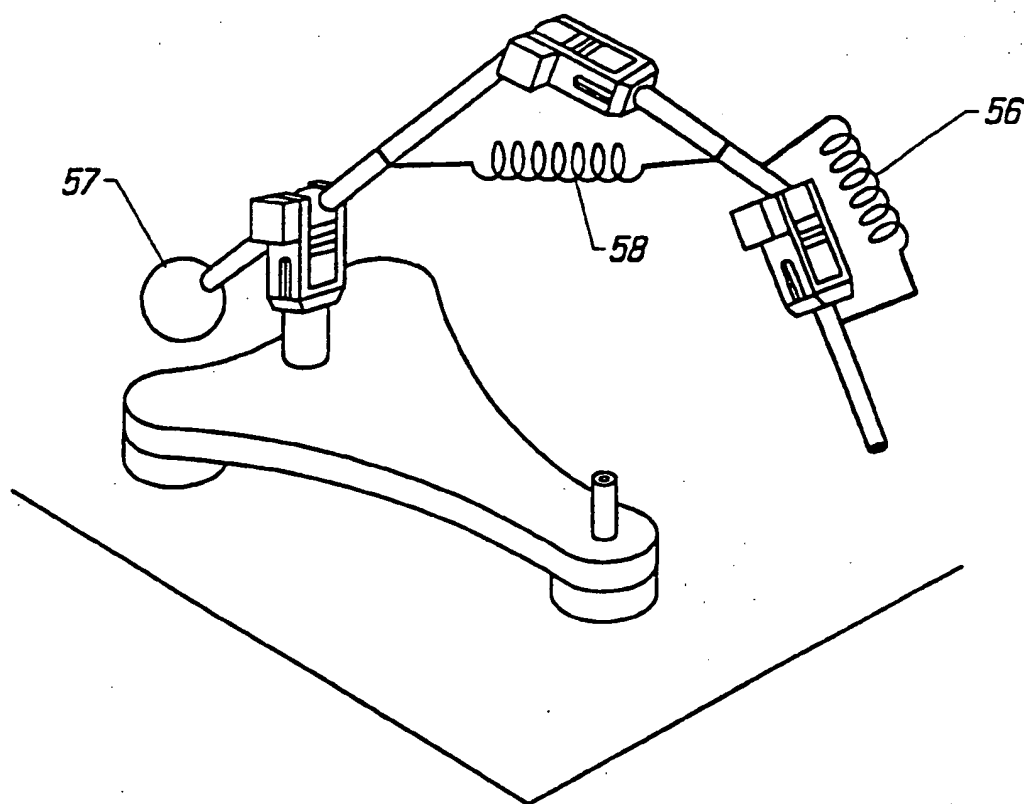


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07851

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : G01B 7/03

US CL : 345/179,156;33/1M,1CC;178/18-

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 345/179,156,157,158,161;33/1M,1CC;178/18;400/475;901/3,4,16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------------|--|---|
| X ----- Y | US,A, 4,593,470 (DAVIES) 10 June 1986, col. 1, lines 11-21; col. 4, lines 8-12, 18-39; col. 4, line 48, through col. 5, line 17. | 1-4, 7, 8, 10, 12-15, 18, 19, 21 ----- 5, 6, 9, 11, 16, 17, 20, 22, 24 |
| X ----- Y | IBM Technical Disclosure Bulletin, "Foot-Operated Mouse", Vol. 28, No. 11, April 1986, page 4763. | 23, 25, 26 ----- 5, 6, 16, 17, 24 |
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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07851

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

APS

search terms: remote control, remote commander, button, switch, power, start, transmit, joint, knuckle, sensor, attitude, pitch, three dimension, 3D, stylus, styli, mechanical linkage